

**EVALUATION OF FRICTIONAL FORCES GENERATED BETWEEN
THREE DIFFERENT LIGATION METHODS WITH FOUR DIFFERENT
SIZES OF ORTHODONTIC ARCHWIRES - AN IN VITRO STUDY”**

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CERTIFICATE

*This is to certify that **DR. R. RANGANATHAN**, post graduate student(2008-2011) in the Department Of Orthodontics & Dentofacial orthopedics , J.K.K.Nataraja Dental College, Komarapalayam, Namakkal Dist – 638183, Tamilnadu. Has done the dissertation titled*

“EVALUATION OF FRICTIONAL FORCES GENERATED BETWEEN THREE DIFFERENT LIGATION METHODS WITH FOUR DIFFERENT SIZES OF ORTHODONTIC ARCHWIRES – AN IN VITRO STUDY.”

*Under my direct guidance and supervision for the partial fulfillment of the regulations laid down by **THE TAMIL NADU DR.M.G.R MEDICAL UNIVERSITY, CHENNAI**, for M.D.S BRANCH – ORTHODONTICS & DENTOFACIAL ORTHOPEDICS DEGREE EXAMINATION.*

It has not been submitted (partial or full) for the award of any other degree or diploma.

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INTRODUCTION

Orthodontic treatment mechanics with pre-adjusted edgewise appliance represent an effective method for controlled orthodontic tooth movement. Orthodontic tooth movement during sliding mechanics is achieved by a force given by archwire or external force applied for the tooth movement. Frictional force produced at bracket/archwire/ligature unit tends to contrast the desired tooth movement.

High frictional forces due to the interaction between bracket and the guiding archwire affect the treatment outcome in a negative manner. By reducing the friction at the bracket /archwire/ ligature interfaces, lower levels of force can be applied. We can obtain an optimal biological response for effective tooth movement.

Friction can be defined as the resistance to motion, when it is attempted to slide one surface over another with which it is in contact (Tweeny and Hughes, 1961).³⁰ Static frictional force is defined as the smallest force needed to start a motion of solid surfaces with respect to each other and Kinetic frictional force is defined as the force needed to resist the sliding motion of one solid object over another at a constant speed.

The frictional force is derived from the summation of coefficient of friction and a force acting perpendicular to the contacting surfaces. In order for one object to slide against the other, the force applied needs to overcome the frictional resistance. Therefore when sliding mechanics is used, some of the applied force is dissipated as friction, and the remaining is transferred to the

supporting structures to mediate tooth movement. Maximum biologic tissue response occurs only when the applied force is of sufficient magnitude to adequately overcome friction and lie within the optimum range of forces necessary for the movement of the tooth. It is important that frictional forces should be eliminated or minimised when orthodontic tooth movement is being planned.

For a better understanding of friction generated during sliding, it is important to know the role of various factors in the origin of friction. They can be classified as Physical and Biologic factors.²⁸ 1) Physical factors which include A) Bracket wire clearance B) Arch wire size C) Archwire section D) Torque at bracket wire interface E) Surface condition of archwire & bracket slot F) Bracket & arch wire material G) Bracket slot width H) Bracket type (conventional or self ligating) I) Type & force of arch wire ligation 2) Biologic factors are saliva, plaque, acquired pellicle.

As can be seen from the above mentioned information, a number of factors have been implicated in influencing frictional forces during orthodontic tooth movement. Among these, the effects of archwire material, dimensions, and bracket material have been extensively investigated. The method of archwire ligation appears to be an important determinant in the generation of friction, yet relatively very few studies have looked at this interaction.

Elastomeric modules are more popular clinically as they can be applied quickly, economical and are also comfortable to the patient. Elastomeric ligatures are polyurethane based polymers which undergo stress relaxation & slow

hydrolytic decomposition over time. Frictional force reduced in 3-4 weeks time with concurrent decrease in load strength.

Self-ligating brackets are not new to orthodontics. They were introduced in the mid 1930s.⁴³ The first self-ligating bracket, the Russell attachment was introduced in an attempt to enhance clinical efficiency by reducing ligation time. The introduction of self-ligating brackets is a main stream in orthodontics to reduce friction in sliding mechanics.

The term self-ligation in orthodontics implies that the orthodontic bracket has the ability to engage itself to the archwire and is therefore assumed to reduce friction by eliminating the ligation force. These bracket system have a mechanical device built into the bracket to close off the edgewise slot. Two types of self-ligating brackets have been developed: those that have a spring clip that presses against the archwire and those in which the self-ligating clip closes the slot, creating a tube, and does not actively press against the wire. With every self-ligating bracket, whether active or passive, the movable fourth surface of the bracket is used to convert the slot into a tube.

Force of normal ligation can range from 50 to 300g. Elastomeric modules will generate approximately 225g of force with subsequent decay because of elastic relaxation. Self-ligating brackets have been reported to produce the least amount of friction but vary depending on whether the self-ligation mechanism is active or passive.

Recently, an innovative ligature manufactured with a special polyurethane mix by injection moulding technique (unconventional elastomeric ligatures, Slide, Leone orthodontic products, Sesto Fiorentino, Firenze, Italy) was

introduced. These ligatures are completely passive like labial cover of passive self-ligating brackets; thus, it guarantees the same freedom of sliding through the wire. These elastomeric ligatures are used on conventional brackets to produce lower levels of frictional resistance in treatment mechanics with preadjusted edgewise appliance. Once the ligatures are applied on the brackets, the interaction between ligature and bracket slot forms a “tube like” structure which allows the arch wire to slide freely to produce its effect more readily on the dentoalveolar component.

This study compares the frictional forces generated by three different ligation systems that is conventional brackets ligated with conventional elastomeric ligature, conventional brackets ligated with unconventional elastomeric ligatures and passive self ligating brackets with 0.014”, 0.016” Nickel Titanium [Ni-Ti] and 0.017” x 0.025”, 0.019” x 0.025” Stainless Steel [SS] Archwires-In Vitro.

AIMS & OBJECTIVES

- 1) To evaluate the frictional forces produced by two types of Elastomeric ligatures (unconventional elastomeric ligatures and conventional elastomeric ligatures) on conventional brackets with four types of wires, 0.014" Nickel Titanium (Ni-Ti), 0.016" Nickel Titanium (Ni-Ti), 0.017" x 0.025" Stainless Steel wire (SS) and 0.019" x 0.025" Stainless Steel wire (SS).

- 2) To evaluate the frictional forces produced by a Passive Self-Ligating bracket with four types of wires, 0.014" Nickel Titanium (Ni-Ti), 0.016" Nickel Titanium (Ni-Ti), 0.017" x 0.025" Stainless Steel wire (SS) and 0.019" x 0.025" Stainless Steel wire (SS).

- 3) To compare the frictional forces produced by a passive self ligating bracket and two types of elastomeric ligatures-unconventional elastomeric ligatures and conventional elastomeric ligatures on conventional brackets used with four types of wires 0.014" Nickel Titanium (Ni-Ti), 0.016" Nickel Titanium (Ni-Ti), 0.017" x 0.025" Stainless Steel wire(SS) and 0.019" x 0.025" Stainless Steel wire(SS).

REVIEW OF LITERATURE

Robert P.Kusy et al., (1988)³⁶ studied the surface roughness of the orthodontic wires via laser spectroscopy. Surface roughness of orthodontic wires may affect the coefficient of friction i.e sliding mechanics. Four alloy groups were selected for study. Laser spectroscopy was done and it was determined that the wires of four alloy groups do demonstrate different surface roughness. Although surface roughness may influence both the appearance and performance of the wire, it will be necessary to conduct experiments evaluating co-efficient of friction and their effects to elucidate collective effect on performance.

Drescher D et al., (1989)⁸ evaluated the factors affecting the frictional magnitude and also the frictional force between the bracket and archwire. Five wire alloys in five wire sizes were examined with respect to three bracket widths at four levels of retarding force. Factors that affected friction are listed in decreasing order: Retarding force, Surface Roughness of the wire, Wire Size, Bracket Width and Elastic properties of the wire. They concluded that the mesiodistal force along an arch wire must exceed the frictional force to produce tooth movement.

Sunil Kapila et al., (1990)⁴⁴ investigated the effects of wire size and alloy on frictional force generated between bracket and archwire during in vitro translatory displacement of bracket relative to the wire. Stainless Steel, Cobalt Chromium, Nickel Titanium, and Beta-Titanium wires of several sizes were tested in narrow single, medium twin and wide twin stainless steel brackets. The wires were ligated into the brackets and bracket movement along the wire was implemented by a mechanical testing instrument. They concluded that the

increase in wire size generally resulted in increased bracket-wire friction and narrow single brackets were associated with lower amount of friction than wider brackets.

Padmaraj V.Angolkar et al., (1990)²⁸ have done a study to determine the frictional resistance offered by ceramic brackets used in combination with wires of different alloys and sizes during in-vitro translatory displacement of brackets. Stainless Steel (SS), Cobalt-Chromium, Beta-Titanium, Nickel-Titanium wires of different cross-sectional sizes were tested with medium-twin monocrystalline ceramic brackets and the frictional force was recorded. Wire friction in ceramic brackets increased as the wire size increased. Rectangular wires, Beta-titanium wires and Ni-Ti were associated with higher frictional forces. Wires in ceramic brackets generated significantly stronger frictional force than did wires in SS brackets.

Tatsuya Shibaguchi et al., (1991)²⁰ investigated the nature of friction between orthodontic wire and various ceramic brackets. The amount of tooth movement with metal and ceramic brackets was measured, and the wire surfaces were examined microscopically immediately after artificial tooth movement. The amount of tooth movement with metal and ceramic brackets was significantly less than that of metal bracket. The wire surfaces were scratched more obviously by ceramic brackets than by metal bracket. Slot surfaces and edges of the ceramic brackets were substantially more porous and rougher than those surfaces of the metal bracket. These material differences between metal and ceramic brackets significantly affect the efficiency of orthodontic tooth movement.

Robert Kusy, et al (1991)³¹ evaluated the co-efficient of friction in dry and wet states for stainless steel, Cobalt-Chromium, Nickel-Titanium, And Beta-

Titanium wires against either Stainless steel or Polycrystalline Alumina brackets. A 0.010 inch stainless steel wire pressed each archwire into the 0.018'' x 0.022'' bracket slot at 34⁰C. In the dry state and regardless of slot size, the mean kinetic coefficients of friction were smallest for the all-stainless steel combinations and largest for the beta-titanium wire combinations. The coefficients of polycrystalline alumina bracket combinations were generally greater than the corresponding combinations that included stainless steel brackets. In the wet state, the kinetic coefficients of all-stainless steel combinations increased upto 0.05 over the dry state. In contrast all beta-titanium wire combinations in the wet state decreased upto 50% of the values in the dry state.

Nigel G. Taylor, Keith Ison, (1996)²⁶ had done a study to evaluate frictional resistance between orthodontic brackets and archwires in the buccal segments. This in vitro study used an Instron testing machine to assess frictional forces for three types of 0.022 x 0.028 inch brackets; Preadjusted premolar Stainless steel brackets, Activa brackets, and Speed brackets. Active brackets produced the least friction for all wires tested. Speed brackets with round wires showed little frictional force while rectangular wires gave rise to higher frictional forces. Ligation with loosely placed ligatures or stretched modules reduced frictional forces in standard straight wire brackets, the reduction being greatest for round wires.

M.G.Duncanson et al., (1998)²³ evaluated the effects of frictional resistance in different bracket-wire combination and second order deflections or kinetic friction. Thirteen different brackets were evaluated with six different sizes and shapes of Stainless Steel orthodontic wire, for four second order deflections. Bracket movement and frictional forces were recorded. It was found

that kinetic frictional force increased for every bracket wire combination as the second order deflection increased and friction also increased with an increase in wire size. Bracket designs that limited the force of ligation on the wire generated less friction at low second order deflections.

Pizzoni L et al., (1998)³⁰ studied the friction induced by self-ligating brackets on stainless steel and beta titanium wires, both in round and rectangular cross-section. They found that round wires had a lower friction than rectangular wires, the beta titanium wires had a markedly higher friction than stainless steel wires, friction increased with angulation for all bracket/wire combinations. The self ligating brackets had a markedly lower friction than conventional brackets at all angulations, and self-ligating brackets closed by the capping of a conventional design, exhibited a significantly lower friction than self -ligating brackets closed by a spring.

Susan Thomas et al., (1998)⁴⁵ investigated the frictional characteristics of two types of self ligating brackets and two types of pre-adjusted edgewise brackets tied with elastomeric ligatures. Five combinations of archwire and material were used for this study. The wires were drawn through the brackets and the frictional resistance was measured using an Instron testing machine. The result revealed that Damon brackets demonstrated the lowest friction for all dimensions of test wires. With all brackets the nickel-titanium wires produced a higher frictional resistance than stainless steel wires. It was concluded that Self-ligating brackets produce less frictional resistance than Elastomerically-Tied Pre-adjusted edgewise brackets.

Rupali Kapur, Pramod K. Sinha (1999)³⁷ measured and compared the level of frictional resistance generated between titanium and stainless steel

brackets. Both 0.018 and 0.022 inch slot size edgewise brackets were tested with different sized rectangular stainless steel wires in a specially designed apparatus. A completely randomized design (one way) ANOVA was used to test significant differences among the three bracket/wire types in the 0.018 and 0.022 inch slot sizes. The titanium brackets showed lower static and kinetic frictional force as the wire size increased, whereas stainless steel brackets showed higher static and kinetic frictional force as the wire size increased.

Brian P. loftus et al., (1999)⁵ evaluated the friction during sliding tooth movement in various bracket-archwire combinations. Frictional forces during simulated sliding tooth movement were measured with a model that was representative of the clinical condition. Conventional and self-ligating stainless steel brackets, conventional ceramic brackets, and ceramic brackets with a stainless steel slot, were tested with 0.019 x 0.025-inch archwire of stainless steel, nickel titanium, and beta titanium. No significant interaction was found between the bracket and the arch wires. However, conventional ceramic brackets generated significantly higher friction than other brackets tested. Beta- titanium archwires produced higher frictional force than nickel titanium archwires.

Rupali Kapur, Parmod K. Sinha (1999)³⁸ measured and compared the level of frictional resistance generated with a non-repeated and repeated experimental design to evaluate whether the wear in the bracket slot will influence frictional resistance. Both 0.018 and 0.022 inch slot size edgewise brackets were tested and the frictional resistance was measured on an Instron Testing Machine. A repeated measures ANOVA test was used to determine differences among the 10 individual bracket wire specimens for each combination to study the influence of wear on static and kinetic frictional force.

The results showed that there was a distinct trend for the mean frictional force to be higher with the repeated use of the brackets.

Scott W. Zufall, Robert P. Kusy (2000)⁴¹ conducted a study to determine the Sliding Mechanics of Coated Composite wires and the development of an engineering model for binding. Prototype composite wires were tested against stainless steel and ceramic brackets in the active and passive configurations. Kinetic coefficient of friction values were determined to quantify sliding resistances as functions of the normal forces of binding. The mean binding coefficient was the same as that of uncoated wire couples. Although penetrations through the coating were observed on many specimens, the glass-fibre reinforcement within the composite wires was undamaged for all the conditions tested.

Robert P. Kusy (2000)³⁴ In this study material innovations were reviewed within the context of ongoing biomechanical developments that relate the critical contact angle of second order angulations to the overall resistance to sliding(RS). RS is partitioned into classical friction (FR), elastic binding (BI), and physical notching (NO). The angulation at which NO occurs is introduced as a second boundary condition. Given this scientific backdrop, material modifications are sought that reduce RS. Approach include minimizing kinetic coefficients within the context of FR. Stabilising second order angulations should provide more efficient and effective sliding mechanics by developing innovative materials in which stiffness varies without changing wire or bracket dimensions.

D.J Michelberger et al., (2000)⁷ investigated the friction and wear pattern of orthodontic brackets and archwires in the dry state. Stainless Steel brackets tested with 0.016 inch flat stainless steel wire surface recorded the lowest

coefficient of static friction. Mean, whereas titanium brackets paired with 0.016" flat ion-implanted beta-titanium wire surfaces produced the highest mean. SS brackets had a significantly lower coefficient of friction than the titanium brackets for all wires. Ion-implanted beta titanium wire generally had significantly larger coefficient than stainless steel wires. Round SS wires demonstrate lower coefficient of static friction than flat SS wire surfaces.

Robert P. Kusy et al., (2000)³³ had done a study to determine the effect of titanium brackets in orthodontic treatment. After each wire was ligated into a bracket with 0.010" stainless steel wire (SS), both SS wire and beta-titanium wire were introduced into the titanium brackets at 34°C in both dry and wet conditions. In the passive configuration, as the angulation was increased from 0° to 11° and the normal force was maintained at 0.2 kg, the resistance to sliding (RS) values increased by 208g for SS versus SS, by 229g for SS versus titanium, by 185 g for beta-titanium versus titanium. When the normal force was increased to 1 kg, the resistance to sliding values increased to 277g, 246g, 245g respectively. Although RS increased with angulations and normal force, the passive layer did not breakdown. Titanium brackets remained comparable to stainless steel brackets in active configuration.

Joon-No-Rhee et al., (2001)¹⁸ explored the difference between friction and frictionless mechanics with a new Typodont simulation system-maxillary canine retraction. The efficiency of the maxillary canine retraction was compared with the sliding mechanics and a canine retraction spring. The patterns of tooth movement obtained with both of these mechanics were measured. Friction mechanics were superior to frictionless mechanics in terms of rotational control and dimensional maintenance of the arch. Frictionless mechanics were

shown to be more effective at reducing tipping and extrusion. The observed difference between the two methods was relatively small in terms of their clinical significance. In conclusion, this study indicated that friction and frictionless mechanics performed similarly.

Glenys A.Thorstenon and Robert P.Kusy (2001)¹² compared the resistance to sliding of self-ligating brackets with conventional stainless steel twin brackets with second order angulation in dry and wet states. The frictional properties of conventional stainless steel (SS) brackets were coupled with rectangular SS archwire and ligated with SS ligatures and the closed self-ligating brackets with the same archwire were compared. Open self-ligating wires ligated with SS wire was used as control. It was concluded that conventional brackets exhibited similar frictional resistance as the open self ligating brackets, whereas closed self ligating brackets exhibited no friction. In the active configuration, at all angles, the resistance to sliding of the closed self ligating brackets were lower than those of the conventional brackets because of the absence of ligation.

Robert P Kusy, John Q Whitley (2001)³² compared the frictional resistance of 2 metal-lined ceramic brackets with 2 conventional stainless steel brackets in vitro. In method 1, second -order angulation was varied from 0° to 12° with normal ligature force constant at 0.3 kg. In method 2, the ligature force was varied from 0° to 11°. All couples were evaluated at 34° using the same size stainless steel archwire and ligature wire. In the passive region, the static and kinetic frictional forces and coefficients of frictions were key parameters. In the active region, the static and kinetic binding forces and co-efficients of friction were key parameters. From outcomes of methods 1 & 2, the 3-dimensional frictional maps were constructed in the dry and wet states from which the

frictional resistance could be determined at any ligature force or second order angulations. Those three dimensional maps showed that metal-lined ceramic brackets can function comparably to stainless steel brackets. These metal-lined ceramic brackets will provide not only good aesthetics but also minimal friction.

Glenys A. Thorstenson, Robert P. Kusy (2002)¹⁰ compared the resistance to sliding between different self-ligating brackets with second order angulations in the dry and wet states. Resistance to sliding (RS) was investigated for 3 self-ligating brackets having passive slides and 3 self-ligating slides having active clips. For all cases stainless steel archwire was drawn through the bracket at a rate of 10mm/minute. For each bracket RS was measured at 14 second order angulations, ranged from -9^0 to $+9^0$. Both the dry and wet states were evaluated at 34^0c . From dimensional measurements, critical contact angle was determined for all products from 3 degree to 5 degree. Generally speaking at second order angulations that exceeded the critical angle, brackets with active clips that had a low critical angle had more RS than bracket with active clips that had a low critical angle. Bracket with passive slides that had a high critical angle exhibited the lowest RS. Self-ligating brackets produce frictional forces that are more reproducible than conventional ligated SS brackets.

Brian K. Rucker et al., (2002)⁴ compared the Sliding Mechanics of Multi stranded SS wires with Single stranded levelling wires in the passive and active regions when dominated by classical friction and elastic binding respectively. Tests were done in both dry and wet conditions. The rectangular wire had 3 and 8 stranded configuration. When a ligature force of 150g was applied and second order angulations varied from -12^0 to 12^0 , each wire was translated relative to its bracket as the drawing force was digitally recorded. In the passive region, the co-

efficient of friction in the wet state were same as, lower than, greater than in the dry state for single stranded SS, single stranded Ni-Ti, multi stranded SS wires. In the active region, the coax (6-stranded) wires had a low friction, triple (3 Stranded) and rect8 (8 stranded) wires had a midrange friction, rectangular wires had a high friction. The coefficient of binding and resistance to sliding were not affected by saliva and were proportioned to the wire stiffness.

Glenys A. Thorstenson et al., (2002)¹¹ have done a study to evaluate the effects of arch-wire size and material on the resistance to sliding of self-ligating brackets with second order angulations in dry state. Four design of stainless steel brackets were coupled with five types of arch-wires. The resistance to sliding (RS) of each arch-wire- bracket couple was measured at second order angles from -9° to $+9^{\circ}$ and inter bracket distance of 8 and 18mm between the test bracket and adjacent bracket. When clearance exists, the RS is negligible for SS brackets with slides coupled to any size of wire as well as for those with clips when coupled with wires that do not contact the clips. Once the wire attains a certain size and contacts the clip, the RS depends on the arch-wire size, the bracket design, and the materials of the couple. When the clearance disappears, the RS increased proportionally with second order angle.

Robert P. Kusy et al., (2002)³⁵ have done a study to understand the principles of sliding mechanics without being distracted by the chatter from indefinable vibrations. The friction can occur because the bracket-arch wire ligature combination in some way produces a resistance to sliding. Methods to reduce static frictional forces are 1) Backing off quarter turn on ligatures after tying them. 2) Choosing bracket designs that reduce the contact point between arch-wire and ligations. 3) Using SS brackets with passive clips or active

springs. Vibration in motion creates force. All forces have magnitude, directions and point of applications. These vary from 1000s of repetitions/second and minute magnitudes of force to fractions of cycle/min and hundreds of Newtons of force that pushes, pulls, twists and turns either aiding or sometimes hampering their motion. It was said that the practitioner and his/ her sliding mechanics will determine the prevailing force.

Laura R. Iwasaki et al., (2003)²¹ had done a study to determine the clinical ligation forces and intraoral ligation during sliding on a stainless steel archwire. This study examined the effect of bracket ligation forces and measured the friction when sliding a bracket along archwire. Nested analysis of variance and Tukey HSD tests determined the effects of ligation type and environmental variables. No significant differences were found between ex vivo and intraoral μ_a (co-efficient of static friction) values for tight and loose SS ligation. Intraoral μ_a values for elastic ligation were significantly greater than ex vivo μ_a values. The results suggested that vibration introduced by mastication did not eliminate friction when sliding a bracket along arch wire.

Max Hain et al., (2003)²⁴ investigated the effect of ligation method on friction in sliding mechanics and evaluated the efficacy of the new slick elastomeric modules, which are claimed to reduce friction at the module/wire interface. Slick modules were compared with regular Nonslick modules, stainless steel ligatures, and the SPEED self-ligating system. Results showed that saliva lubricated slick modules can reduce static friction and SPEED brackets produced the lowest friction. Loosely tied stainless steel ligatures were found to generate the least friction.

Glenys Thorstenson, Robert P. Kusy (2003)¹³ had done a study to find out the influence of Stainless Steel Inserts on the resistance to sliding of aesthetic brackets with second order angulations in the dry and wet states. The resistance to sliding were measured in both dry and wet states at 32 second-order angles between -12^0 and $+12^0$. When clearances no longer existed between the walls and brackets and the archwires, the resistance to sliding for the aesthetic brackets with and without inserts generally increased with angulations at a rate equal to or greater than that of SS brackets, except for the polycarbonate brackets in the dry state. For the polycrystalline alumina brackets without inserts, the resistances to sliding increased rapidly and nonlinearly as angulations increased. It was concluded that addition of these particular SS brackets did not considerably improve the resistance to sliding over those brackets without inserts.

Glenys A Thorstenson, Robert P Kusy (2003)⁹ had done a study to evaluate the effect of ligation type and method on the resistance to sliding of orthodontic brackets with second order angulations in dry and wet states. Rectangular stainless steel arch-wires were coupled with four SS bracket designs; 1) mini diamond twin, 2) versa T, 3) shoulder 4) synergy. For all designs, the value of resistance to sliding (RS) were measured at five normal forces and 32 second order angulations in the dry and wet states. In both states, the coefficient of friction was similar for the 1, 2 & 3, but values of shoulders were slightly greater than other 3 designs. In the passive configuration, shoulder and synergy brackets showed reduced RS when the rings were not in contact with the archwires. In the active configuration, the behavioural patterns of the brackets were not influenced by the ligation methods. Thus, these different

ligation types and methods only affected the classical frictional component of RS in the passive configuration.

Balvindar Khambay et al., (2004)³ investigated the effect of elastomeric type and stainless steel ligature on frictional resistance using a validated method. To assess the validity SS, TMA wires were used in combination with self-ligating Damon bracket and conventional pre-adjusted edgewise bracket without ligature. Then the four types of elastomeric modules ligated to the pre-adjusted SS bracket. The specimens are tested in the presence of human saliva and the frictional forces were recorded. It was confirmed by the result that there is no consistent pattern in the mean frictional forces across the various combinations of wire type, size and ligation method. Use of passive self ligating brackets is the only method of almost eliminating friction.

Ji-Hoon Park et al., (2004)¹⁶ conducted a study with a new measuring method (pin on disc friction tester) for the measurement of the frictional force between the lingual brackets and the arch-wires. Two brands of lingual brackets and one brand of labial bracket with a 0.018-inch slot size were used. Arch-wires of three alloys: stainless steel, cobalt-chromium, beta-titanium with 0.016 x 0.022- and 0.017 x 0.025-inch dimensions were used. Measurements were conducted with an angular velocity of 0.6% for 90 seconds and a normal force of 100g at 25⁰c in an artificial saliva environment. Significant differences in frictional force existed between dry and artificial environments, and the effect varied by bracket-archwire couples. The estimated critical contact angles were greater than the theoretical values.

Sandra P.Henao,Robert P. Kusy (2005)³⁹ Frictional evaluations of dental Typodont models were determined using four Self Ligating designs and a

conventional design. Four replicated typodont models were mounted with a Self Ligating design, and a fifth one with a conventional design that served as control. The first experiment evaluated the manufacturer-suggested archwire system against the respective self-ligating design. Second experiment was conducted to gain more detailed analysis of the designs. The result showed that all self-ligating designs performed with efficiency and reproducibility associated with expectations. It was concluded that the best archwire system can be selected, when taking into account the stiffness, and amount of malocclusion present.

Martyn Sherriff et al., (2005)¹⁴ had done a study to determine whether Super slick module (recently introduced polymeric coated ligature to reduce friction) show lower friction than round and rectangular modules and to put the frictional forces into perspective with a self ligating bracket. Open self-ligating brackets and mono-crystalline brackets were tested with 3 elastomeric modules. Each setup was tested both under dry conditions and after soaking in a water bath for one hour. It was found that the self-ligating brackets demonstrated virtually zero friction. Round modules provided the least resistance to sliding, rectangular the greatest, with superslick in between the two. It was concluded that superslick modules demonstrated greater resistance to sliding than conventional round modules but not rectangular. Self ligating brackets provided the least resistance to sliding of all brackets. Also ceramic brackets demonstrated greater resistance to sliding than stainless steel brackets.

Claudio Chimenti et al., (2005)⁶ evaluated in vitro the effects of variations in the size of elastomeric ligatures on the static frictional resistance generated by orthodontic sliding mechanics under dry conditions. Frictional

forces generated by elastomeric ligatures treated with a lubricating material were also analyzed as well. Instron testing machine was used to assess frictional forces of a 0.019 x 0.022-inch stainless steel rectangular wire that was ligated to a molar convertible tube and to three stainless steel pre-adjusted brackets with elastomeric ligatures of different dimension; small, medium, and large. The static friction produced by these elastomeric ligatures was measured. The small and medium elastomeric ligatures produced significantly less friction than the large ligatures. It was found that lubricated elastomeric ligatures generated significantly smaller frictional force than the non-lubricated ligatures.

Simono Tecco et al., (2005)⁴² used a specially designed apparatus that included 10 aligned brackets to compare the frictional resistance generated by conventional stainless steel brackets, self-ligating Damon SL 2 brackets and time plus coupled with stainless steel, nickel-titanium and beta-titanium archwires. All brackets had a 0.022-in slot, and five different sizes of orthodontic wire alloys used. Each bracket-archwire combination was tested 10 times, and each test was performed with a new bracket -wire sample. The analysis of various bracket-archwire combination showed that Damon SL 2 brackets generated significantly lower friction than the other brackets when tested with round wires and significantly higher friction than Time Plus when tested with rectangular archwires. All brackets showed higher frictional force as the wire size increased.

Balvindr Khambay et al., (2005)² had done a study to determine the mean tensile forces of four different elastomeric modules, the archwire seating force of different ligation methods and its effect on frictional resistance. Each module (Purple, Grey, Alastic, Superslick) was extended by 5mm using two hooks

attached to a load cell to determine the mean tensile force. To assess the median archwire seating force, a maxillary premolar bracket was welded to a sheet of stainless steel (SS) and glued to Perspex block and the experiment was conducted. Grey modules produced lowest median arch wire seating force whereas stainless SS ligatures produced the highest forces. SS ligatures with either wire produced the lowest mean frictional forces, whereas grey modules produced significantly higher forces. Thus the force with which the wire was seated into the bracket did not seem to be related to the subsequent amount of mean frictional force produced.

Tiziano Bacetti, Lorenzo Franchii, (2006)⁴⁷ compared the frictional forces generated by new unconventional passive elastomeric ligature (UEL) and conventional elastomeric ligature (CL) under dry conditions. An experimental model reproducing the right buccal segment of the upper arch and consisting of five stainless steel 0.022-inch pre-adjusted brackets was used to assess both static and kinetic frictional forces produced by CL and UEL. The frictional forces generated by 0.019 x 0.025-inch stainless steel wire with the two types of elastomeric ligatures were recorded by sliding the wire into the aligned brackets. The amount of both static and kinetic friction was minimal in UEL group in the presence of aligned brackets with both types of wires. The amount of both static and kinetic frictions in the presence of a misaligned canine bracket in the UEL group was less than half of that shown by the CL group. It is concluded that passive ligature system is able to produce significantly lower levels of frictional forces.

Lorenzo Franchi, Tiziano Baccetti (2006)²² compared the forces generated by a new non-conventional elastomeric ligature (UEL) and

conventional elastomeric ligature (CEL) during levelling and aligning phase. The testing model consisted of 5 stainless steel pre-adjusted brackets. The force generated by 3 wires of different sizes (0.012, 0.014, 0.016 super elastic nickel-titanium) with two types of elastomeric ligatures at different amounts of upward canine alignment were recorded. Significant differences between UEL and CEL were found for all tested variables with the exception of 0.014- and 0.016-in wires at canine misalignment of 1.5mm. A noticeable amount of force was generated with UEL at all canine positions with all 3 wire sizes. With 4.5mm of canine misalignment, the average amount of released force with CEL was approximately zero.

Jung-Yul Cha et al., (2007)¹⁹ had done a study to compare the level of frictional resistance of conventional and silica-insert ceramic brackets in various bracket-wire combinations and angulations. Four types of ceramic bracket were examined: 1) Polycrystalline Alumina Bracket (PCA-C), 2) Polycrystalline Alumina Bracket with a Silica Layer (PCA-S) 3) Polycrystalline Alumina bracket with a stainless steel slot (PCA-M), 4) Mono-crystalline Sapphire bracket (MCS). A conventional SS bracket was used as control. The static and kinetic frictional resistance in four bracket-wire angulations was examined under elastic ligature in the dry state. The frictional resistance generated by the PCA-S bracket was significantly lower than that generated with the other ceramic brackets, and was similar to that of stainless steel bracket. The PCA-S bracket showed the lowest frictional resistance with both the stainless steel and beta-titanium wires at zero angulations. The frictional resistance to sliding increased rapidly and non-linearly when the bracket wire angulation was greater than 5°. The PCS-S bracket showed the lowest frictional resistance from 5° to 15° of

angulation. The MCS bracket demonstrated the highest increase in frictional resistance. Thus it is concluded that PCA-S showed minimal frictional resistance among the ceramic brackets, and was comparable to the conventional SS bracket. The silica layer and rounded edges of the ceramic slot lowered frictional resistance considerably.

Toru Deguchi, et al., (2007)⁵⁰ compared the amount of canine movement and the retraction time between brackets with clear snap and brackets with stainless steel ligature wires for three different levels of retraction force. A sample of 30 patients was used. After initial levelling, the canine was retracted using a 50g, or 150g closed coil spring. The canine on one side was chosen at random, and clear snap was attached to the bracket during the retraction period. The other side was used as control. Amount of canine retraction was measured using a vernier calliper. Statistical analysis was performed by analysis of variance. The average canine retraction time was approximately 2 to 3 months less in all experimental groups compared to the control groups. There was no significant difference in duration of canine retraction among the experimental groups. A greater amount of mean total canine movement was observed in all experimental groups compared to the control groups. It was suggested that with the use of clear snap, less than 50 g of force may effectively retract a canine.

Tiziano Bacetti, et al., (2008)⁴⁹ compared the forces resulting from four types of bracket/ligature combinations; ceramic brackets and stainless steel brackets combined with unconventional elastomeric ligatures(UEL) and conventional elastomeric ligatures(CEL) during the levelling and aligning phase of orthodontic therapy. The forces generated by a 0.014-inch super-elastic nickel titanium wire in the presence of either UEL or CEL bracket/ligature systems at

different amounts of upward canine misalignment were recorded. Significant differences were found between UEL and CEL systems for all tested variables. The average amount of recorded force in the presence of CEL was negligible with 3.0 mm or greater of canine misalignment. It was concluded that type of ligature used influenced the actual amount of force released by the orthodontic system significantly more than the type of bracket used.

Paola Gandini, et al.,(2008)²⁹ have done a study to test the hypothesis that there is no difference between the frictional forces produced by passive Self-Ligating Bracket(SLB) in vitro and a conventional bracket(CB) used with two types of elastomeric ligatures. The brackets, wires and ligation methods used in vitro were a passive SLB and a CB used with two types of elastomeric ligatures (conventional elastomeric ligatures CEL and unconventional elastomeric ligatures UEL). The bracket ligation systems were tested with two types of wires (super elastic nickel titanium and stainless steel wire). Resistance to sliding of the bracket/wire/ligature systems was measured with an experimental model mounted on the crosshead of Instron testing machine with a 10N load cell. Each sample was tested 10 consecutive times under a dry state. The result showed that resistance to sliding increased significantly when CEL on CB was used with both wires. UELs may represent a valid alternative to passive SLBs for low friction biomechanics.

Simona Tecco et al., (2009)⁴³ compared the frictional resistance between archwires of different sizes, cross-section and alloy and brackets ligated with low-friction or conventional ligatures. A total of 10 stainless steel brackets, 0.022-in slot, and various orthodontic archwires, ligated with low-friction ligatures or conventional ligatures were used. Each bracket-archwire

combination was tested 10 times in the dry state at an ambient temperature of 34°C. It was found that low-friction ligatures with round archwires showed statistically lower frictional resistance than did conventional ligatures. When coupled with 0.016 x 0.022-in Ni-Ti and SS, no statistically significant difference was observed among the four groups. When coupled with 0.017 x 0.025-in archwires, low friction ligatures showed statistically significantly greater frictional resistance than conventional ligatures. When coupled with 0.019 x 0.025-in Ni-Ti, low friction ligatures showed greater frictional resistance than did conventional ligatures, but no difference among the four groups was observed with 0.019 x 0.025-in SS. Thus it was concluded that low-friction ligatures show lower friction when compared with conventional ligatures when coupled with round archwires, but not when coupled with rectangular ones.

Tiziano Bacetti et al., (2009)⁴⁸ compared the force produced by different nonconventional bracket or ligature systems during alignment of apically displaced teeth. An experimental model consisting of five brackets was used to assess the forces released by the seven different ligature bracket systems. Comparison between different types of bracket/wire/ligature systems were carried out by means of ANOVA on ranks with the Dunnett's post test. The result showed that when correction of a misalignment greater than 3mm is attempted, a noticeable amount of force for alignment is generated by passive SLBs and nonconventional elastomeric ligature bracket systems, and a null amount of force is released in the presence of conventional elastomeric ligature on conventional brackets. It was concluded that when minimal apical displacement is needed (1.5mm), the difference in performance between low-

friction and conventional system are minimal. These differences become significant when correction of a misalignment greater than 3.0 mm is attempted.

Robert J. Nikolai et al., (2009)⁴⁴ examined the influence of third order torque on kinetic friction in sliding mechanics involving active and passive Self-Ligating Brackets. Wire slot frictional forces were quantified and compared across five sets of brackets and tubes within a simulated posterior dental segment with -15° , -10° , -5° , 0° , $+5^{\circ}$, $+10^{\circ}$, $+15^{\circ}$ of torque placed in the second premolar bracket, a working archwire was pulled through the slots. Increasing the torque produced significant increase in frictional resistance with all five sets of brackets and tubes. At 0° and 5° of torque, generally less friction was created within the passive than within the active self-ligating bracket sets, and the conventional bracket sets with elastomeric ligation generated the most friction. At 10° of torque, apparently with wire-slot clearance eliminated, all bracket-and-tube sets displayed similar resistances, with one exception at $+10^{\circ}$. At 15° of torque, one active set and one passive set produced significantly larger frictional resistance than the other three sets. Thus it was concluded that third order torque in posterior dental segments can generate frictional resistance during anterior retraction with the archwire sliding through self-ligating bracket slots. With small torque angles, friction is less with passive than with active self-ligating brackets, but bracket design is a factor. Frictional forces are substantial, regardless of ligation if the wire-slot torque exceeds the third-order clearance.

Sayeh Ehsani et al., (2009)⁴⁰ compared the frictional resistance between orthodontic self-ligating brackets and conventionally ligated brackets in vitro. Several electronic databases were searched without limits. In vitro studies that addressed friction of self-ligating brackets compared with conventionally ligated

brackets were selected and reviewed. On Comparison with conventional brackets, self-ligating produced lower friction when coupled with small round archwires in the absence of tipping and/or torque in an ideally aligned arch. Sufficient evidence was not found to claim that with large rectangular wires, in the presence of tipping and/or torque and in arches with considerable malocclusion, self-ligating brackets produce lower friction compared with conventional brackets.

John C. Voudouris et al., (2010)¹⁷ tested the frictional resistance forces (FRS) generated between several archwires and (1) interactive self-ligating (ISL) brackets and (2) conventionally ligated (CL) brackets. Frictional forces produced between three different archwire combinations and self-ligating (SL) and CL brackets were evaluated in dry environment. The three ISL brackets tested were In-Ovation-C, In-ovation-R, and Damon 3. The three CL brackets were Mystique with Neo clip, Clarity, and ovation. The result showed that ISL brackets exhibited the lowest frictional forces irrespective of the bracket material and the wire size, and CL brackets exhibited consistently higher frictional forces. Mystique with Neo Clip produced the lowest frictional resistance of all brackets. The In-Ovation-C brackets demonstrated significantly lower frictional resistance than the SL brackets In-Ovation-R and Damon-3 as well as the CL brackets Clarity and Ovation. It is concluded that ISL ceramic brackets produced the lowest frictional resistance of all the self-ligating brackets. The CL ceramic brackets produced the greatest friction.

Isabella Silva Viera Marques et al., (2010)¹⁵ investigated the degree of debris, roughness, and the friction of stainless steel orthodontic archwires before and after clinical use. For eight individuals, two sets of three brackets were

bonded from the first molar to the first premolar. A passive segment of 0.019 x 0.025-inch stainless steel archwire was inserted into the brackets and tied by elastomeric ligature debris level, roughness, and frictional force were evaluated as received and after 8 weeks of intraoral exposure. There was significant increase in the level of debris, roughness of orthodontic wire, and friction after friction after intraoral exposure. Significant positive correlations were observed between these three variables. Stainless steel rectangular wires, when exposed to the intra-oral environment for 8 weeks, showed a significant increase in degree of debris and surface roughness, causing a increase in friction between the wire and the bracket during the mechanics of sliding.

Padhraig S.Fleming, ama johal, (2010)²⁹ evaluated the clinical differences in relation to the use of self-ligating brackets in orthodontics. Electronic databases were searched. Randomized control trials(RCTs) and controlled clinical trials(CCTs) investigating the influence of bracket type on alignment efficiency, subjective pain experience, bond failure rate, arch dimensional changes, rate of orthodontic space closure, periodontal outcomes and root resorption were selected. Six RCTs and 1 CCTs were identified. Meta-analysis of the influence of bracket type on subjective pain experience failed to demonstrate a significant advantage for either type of appliance. Thus at this stage there is insufficient high-quality evidence to support the use of self-ligating fixed orthodontic appliance systems or vice versa.

Amy Archambault et al., (2010)¹ conducted an experimental study to compare the torque expression between stainless steel, titanium molybdenum alloy(TMA), and copper nickel titanium wires in metallic self-ligating brackets. The force moment providing rotation of tooth around the x-axis is referred to as

torque expression in orthodontic literature. Many factors affected torque expression including the wire material characteristics. With a warm-gear-driven torquing apparatus, wire was torqued while a bracket mounted on a six-axis load cell was engaged. Three 0.019 x 0.0195 inch wire stainless steel, titanium molybdenum alloy, copper nickel titanium, and three 0.022 inch slot bracket combinations were compared. At low twist angles, the differences in torque expression between the wires were statistically significant. At twist angles over 24 degrees, stainless steel wire yielded 1.5 to 2 times the torque expression of TMA and 2.5 to 3 times that of nickel titanium. At high angles of torsion with a stiff wire material, loss of linear torque expression sometimes occurred. It was concluded that stainless steel has the largest torque expression, followed by TMA and then Ni-Ti.

Takeshi Muguruma et al., (2010)⁴⁶ had done a study to test the hypothesis that a diamond like carbon coating does not affect the frictional properties of orthodontic wires. Two types of wire were used, and Diamond-Like Carbon films (DLC) were deposited on the wires. Three types of brackets, a conventional stainless steel bracket and two self-ligating brackets, were used for measuring static friction. When angulations was increased, the DLC-coated wires showed significantly less frictional force than the as-received wires, except for some wire/bracket combinations. The hardness of the surface layer of the DLC-coating wires was much higher than for the as-received wires. The elastic modulus of the surface layer of the DLC-coated stainless steel wire, whereas similar values were found for the nickel-titanium wires. It is concluded that DLC-coating process does reduce the frictional force.

MATERIALS

The following materials were used to collect the data.

▪ BRACKETS

Conventional brackets

- 8 Upper Premolar Pre-adjusted Edgewise Appliance Stainless Steel brackets (four for each group).
- Slot width 0.022" x 0.028"
- -7° Torque
- 0° Tip
- Roth Ovation(3 M Unitek)

Self-ligating brackets (Fig 1)

Four passive self ligating brackets

- Slot width 0.022" x 0.0275" (Smart Clip, 3 M Unitek)

▪ ARCHWIRES

1. 0.014" Nickel Titanium wire[Ni-Ti] Straight length (Fig 5-A)
2. 0.016" Nickel Titanium wire[Ni-Ti] Straight length (Fig 5-B)
3. 0.017" x 0.025" Stainless Steel wire[SS] Straight length (Fig 5-C)
4. 0.019" x 0.025" Stainless Steel wire[SS] Straight length (Fig 5-D)

▪ ELASTOMERICS

1. Conventional Elastomeric Ligature-Silver Medium [3M Unitek] (Fig3)
2. Unconventional Elastomeric Ligature-Silver Medium [Leone Orthodontic Products-Italy] (Fig 4)

- **CUSTOM MADE FRICTION TESTING APPARATUS** (Fig 10)
- **INSTRON Universal Testing Machine[LLYOD]L.R-50K-England** (Fig 9)
- **MISCELLANEOUS** (Fig 8)
 1. Weingart Plier
 2. Bracket Positioner
 3. Mathew's Needle holder
 4. Distal end Cutter
 5. Ligature Tucker
 6. Probe and Explorer.

METHODOLOGY

Brackets were divided into three groups:

Group I : Conventional brackets to be ligated with unconventional modules [Fig-2]

Group II : Conventional brackets to be ligated with conventional modules [Fig-2]

Group III : Passive Self-Ligating Brackets [Fig-1]

All the three groups were further divided into 4 subgroups depending on the wire to be tested.

- A. 0.014” Nickel Titanium (Ni-Ti) [Fig 5-A]
- B. 0.016” Nickel Titanium (Ni-Ti) [Fig 5-B]
- C. 0.017” x 0.025” Stainless Steel (SS) [Fig 5-C]
- D. 0.019” x 0.025” Stainless Steel (SS) [Fig 5-D]

Under each subgroup 10 trials were conducted and they were numbered numerically from 1 to 10.

Sample Preparation:

Custom made friction testing apparatus was specially constructed for this study.

The apparatus was divided into two parts an upper member [Fig-7], and a lower member [Fig-6]

Lower member of the friction testing apparatus [Fig-6]

8mm/6mm thickness steel rectangular rod was customized and was cut into 4 pieces having length of 75mm. They were welded together in the shape of “P” with

one side open, finished and polished to have a smooth surface. Two little vertical holes were drilled on the upper and lower part of the “p” shaped jig for the wire to enter and two horizontal holes were drilled on the open end of the “p” in which two screws were threaded to tighten the wire. This part of the custom made apparatus will be further called as LOWER MEMBER, to be clamped on the immovable clamp of the universal testing machine (Fig-6).

Upper member of the friction testing apparatus: [Fig-7]

12 pieces of steel rod with dimension of 8mm/6mm thickness and 100mm length was cut, finished and polished to have a smooth surface. This will be used for welding the bracket for each group and subgroups. This will be further called as UPPER MEMBER, to be clamped on the movable clamp of the universal testing machine.

Care was taken to make the vertical hole in such a position so that the arch wire was passive when ligated into the bracket slot, which is welded on to the upper member.

Specimen preparation of Conventional brackets with Unconventional modules (Group I) [Fig 11]

4 conventional Stainless Steel Pre-adjusted Edgewise upper premolar brackets were taken. These brackets were welded on the centre of upper member (4 numbers), such that the archwires can slide passively within the bracket slot. Arch wires were ligated with unconventional modules. These would be referred as Group I

Specimen preparation for Conventional brackets with Conventional modules (Group II) [Fig 12]

4 conventional Stainless Steel Pre-adjusted edgewise upper premolar brackets were taken. These brackets were welded on the centre of the upper member (4 numbers), such that the archwires can slide passively within the bracket slot. Arch wires were ligated with Conventional modules. These would be referred as Group II.

Specimen preparation for passive Self-Ligating brackets (Group III) [Fig 13]

4 Passive Self-Ligating Stainless Steel upper premolar brackets were taken. These brackets were welded one on the centre of upper member, (4 numbers), such that the archwires can slide passively within the bracket slot. These would be referred as Group III.

Tests were carried out in Composite Technological Park, Kengeri (Bangalore) by using Instron Universal Testing Machine [LLOYD] L R-50K-England.

Evaluation of friction for Conventional brackets with Unconventional modules (Group I)

The custom made Lower member was clamped tightly to the immovable lower clamp of the universal Testing machine. Each upper member for the Group I was attached to the upper movable clamp of the Universal Testing machine, and was tested for friction with four wires(0.014”Ni-Ti, 0.016” Ni-Ti, 0.017” x 0.025” SS, 0.019” x 0.025” SS). Care was taken so that the archwire/bracket/ligature system was passive.

Each of the 4 brackets, wire and unconventional module combination was tested for 10 trials. Wire and modules were changed for each trial to minimize the

influence of elastic deformation. After the samples were mounted, Traction test was conducted and readings were tabulated for all specimens. (FIG 14-A)

Evaluation of friction for Conventional brackets with Conventional modules (Group II)

The custom made Lower member was clamped tightly to the immovable lower clamp of the universal testing machine. Each Upper member for the Group II was attached to the upper movable clamp of the Universal Testing machine, and was tested for friction with four wires(0.014”Ni-Ti, 0.016” Ni-Ti, 0.017” x 0.025” SS, 0.019” x 0.025” SS). Care was taken so that the archwire/bracket/ligature system was passive.

Each of the 4 brackets, wire and Conventional module combination was tested for 10 trials. Wire and modules changed for each trial to minimize the influence of elastic deformation. After the samples were mounted, traction test was conducted and readings were tabulated for all specimens. (FIG 14-B)

Evaluation of friction for passive Self-Ligating brackets (Group III)

The custom made Lower member was clamped tightly to the immovable lower clamp of the universal Testing machine. Each Upper member for the Group III was attached to the upper movable clamp of the Universal Testing machine, and was tested for friction with four wires(0.014”Ni-Ti, 0.016” Ni-Ti, 0.017” x 0.025” SS, 0.019” x 0.025” SS). Care was taken so that the archwire and self-ligating bracket system was passive.

Each passive Self-Ligating bracket and wire combination was tested for 10 trials. After the samples were mounted, Traction test was conducted and readings were tabulated for all specimens (Fig 14-C).

Traction Test:

Each traction test was conducted at a speed of 6mm/min over a distance of 9.5mm and the following frictional forces were recorded for static friction and kinetic friction at 5mm, 9mm by universal testing machine. All measurements were performed under dry condition at temperature $20 \pm 2^{\circ}\text{C}$.

TABLES

GROUP I: CONVENTIONAL BRACKETS WITH UNCONVENTIONAL MODULES**Table 1: Conventional Brackets with Unconventional Modules
(0.014" Ni-Ti)**

(I) - A

0.014" NiTi	Static	Kinetic		
Trials		5mm	9mm	Max
1	0.01	0	0.34	0.34
2	0.01	0.19	0.19	0.19
3	0	0.49	0.49	0.49
4	0	0	0	0.182
5	0.266	0	0.266	0.266
6	0.05	0.66	0.66	0.66
7	0	0	0	0.72
8	0.1	0.1	0.1	0.100
9	0.05	0	1.1	1.1
10	0.05	0	1.1	1.1

**Table 2- Conventional Brackets with Unconventional Modules
(0.016" Ni-Ti)**

(I - B)

0.016" NiTi	Static	Kinetic		
Trials		5mm	9mm	Max
1	0	0	0.436	0.436
2	0	0	0	0.15
3	0	0	0	0.71
4	0	0	0	0.56
5	0.16	0	0.16	0.16
6	0.16	0	0.16	0.16
7	0	0	0	0
8	0	0.45	0.45	0.450
9	0	0.3	0.3	1.4
10	0	0.5	0.5	0.5

**Table 3- Conventional Brackets with Unconventional Modules
(0.017"×0.025" Stainless steel)**

(I) – C

0.017" x 0.025"SS	Static	Kinetic		
Trials		5mm	9mm	Max
1	0	1.2	0	1.2
2	0	0	0	1.1
3	0	0	0	1.34
4	0	0	0	0
5	0	0	0	0
6	0	0	0	1.3
7	0	0	0	1.1
8	0	0	0	1.21
9	0	0	0	1.2
10	0	0	0	0.800

**Table 4- Conventional Brackets with Unconventional Modules
(0.019"×0.025" Stainless Steel)**

(I) - D

0.019"x 0.025" SS	Static	Kinetic		
Trials		5mm	9mm	Max
1	0.3	0.3	0.3	1.21
2	0.35	0.35	0.35	1.35
3	0	0	0	0.55
4	0	0	0	0.453
5	0	0.8	0.8	0.8
6	0.5	0.5	0.5	0.5
7	0	0	0	0.3
8	0	0	0	1.200
9	0	0.5	0.5	0.5
10	0	0	0	0.7

Table 5- Statistical Analysis of Group-I

0.014” NiTi	Mean	Median	Standard Deviation	Range	Minimum	Maximum
Static	0.09563	0.05	0.142216	0.466	0	0.466
K 5mm	0.294	0	0.569351	1.66	0	1.66
K 9mm	0.7246	0.815	0.624509	1.66	0	1.66
K max	1.07963	1.1	0.657381	2.056	0.1	2.156
0.016” NiTi						
Static	0.032	0	0.067462	0.16	0	0.16
K 5mm	0.226	0	0.365185	0.82	0	0.82
K 9mm	0.35686	0.16	0.4036	0.9886	0	0.9886
K max	1.37796	1.355	0.821889	2.799	0	2.799
0.017” x 0.025”SS						
Static	0	0	0	0	0	0
K 5mm	0.12	0	0.379473	1.2	0	1.2
K 9mm	0	0	0	0	0	0
K max	1.2884	1.55	0.716714	1.934	0	1.934
0.019”x 0.025” SS						
Static	0.115	0	0.191558	0.5	0	0.5
K 5mm	0.245	0.15	0.289108	0.8	0	0.8
K 9mm	0.245	0.15	0.289108	0.8	0	0.8
K max	1.7318	1.65	0.576188	1.59	0.8	2.39

**GROUP II: CONVENTIONAL BRACKETS WITH CONVENTIONAL
MODULES**

**Table 6-Conventional Brackets with conventional modules
(0.014”Ni-Ti)**

(II) – A

0.014” NiTi	Static	Kinetic		
Trials		5mm	9mm	Max
1	0.9	0.9	0.9	1.109
2	0.9	0.9	0.9	3.084
3	2.13	2.13	2.13	2.13
4	0	1.5	0	1.58
5	0.7	0.7	0.7	2.73
6	0.5	0.5	0.5	2.18
7	0.5	0.5	0.5	2.17
8	1.3	1.3	1.3	3.150
9	0	1.7	1.7	1.7
10	1.1	1.1	1.1	2.98

**Table 7-Conventional Brackets with conventional modules
(0.016”Ni-Ti)**

(II) – B

0.016” NiTi	Static	Kinetic		
Trials		5mm	9mm	Max
1	0	0	0	1.799
2	0	2.9	2.9	2.919
3	0.5	0	0	0
4	0	1.381	1.381	1.381
5	0.7	2.828	2.828	2.828
6	0.5	2.6	2.8	2.8
7	0	0.05	1.8	1.8
8	0.8	0.8	2.7	2.700
9	0	0	0	2.6
10	0.2	0	0	2.014

**Table 8-Conventional Brackets with conventional modules (0.017"x0.025"
Stainless steel)**

(II) – C

0.017" x 0.025"SS	Static	Kinetic		
Trials		5mm	9mm	Max
1	0	1.829	1.829	1.829
2	1.359	1.359	1.359	1.359
3	0	1.796	1.796	1.796
4	0	1.346	1.346	1.346
5	0.5	0.5	2.37	2.37
6	0.43	0.43	0.5	2.34
7	0.82	0.82	0.82	2.723
8	0.79	0.79	0.79	3.026
9	0.78	0.78	0.78	3.039
10	0.87	0.87	0.87	2.773

**Table 9- Conventional Brackets with conventional modules (0.019"x0.025"
Stainless steel)**

(II) – D

0.019"x 0.025" SS	Static	Kinetic		
Trials		5mm	9mm	Max
1	0	0	1.058	1.058
2	0.65	0.65	0.65	2.193
3	0.54	0.54	0.54	2.45
4	0.48	1.43	1.43	2.385
5	1.52	0.39	0.39	2.229
6	1.801	0.11	1.801	1.801
7	0.04	1.863	1.863	1.863
8	0.58	0.58	0.58	2.492
9	1.865	0	1.865	1.865
10	0.686	0	0.92	2.832

Table 10- Statistical analysis of Group-II

0.014'' NiTi	Mean	Median	Standard Deviation	Range	Minimum	Maximum
Static	0.803	0.8	0.632351	2.13	0	2.13
K 5mm	1.123	1	0.534957	1.63	0.5	2.13
K 9mm	0.973	0.9	0.620896	2.13	0	2.13
K max	2.2813	2.175	0.694265	2.041	1.109	3.15
0.016'' NiTi						
Static	0.27	0.1	0.323351	0.8	0	0.8
K 5mm	1.0559	0.425	1.272268	2.9	0	2.9
K 9mm	1.4409	1.5905	1.330113	2.9	0	2.9
K max	2.0841	2.307	0.907572	2.919	0	2.919
0.017'' x 0.025''SS						
Static	0.5549	0.64	0.455148	1.359	0	1.359
K 5mm	1.052	0.845	0.501012	1.399	0.43	1.829
K 9mm	1.246	1.108	0.599351	1.87	0.5	2.37
K max	2.2601	2.355	0.644454	1.693	1.346	3.039
0.019''x 0.025'' SS						
Static	0.8162	0.615	0.67688	1.865	0	1.865
K 5mm	0.5563	0.465	0.635581	1.863	0	1.863
K 9mm	1.1097	0.989	0.58609	1.475	0.39	1.865
K max	2.1168	2.211	0.494665	1.774	1.058	2.832

GROUP III- SELF-LIGATING BRACKETS

**Table 11- Self Ligating Brackets
(0.014”Ni-Ti)**

(III) – A

0.014” NiTi	Static	Kinetic		
Trials		5mm	9mm	Max
1	0.05	0.05	0.9	1
2	0.05	0.05	0.05	1
3	0.04	0.61	0.61	0.6105
4	0.7	0	1.92	1.92
5	0	0	0	1.902
6	0	0	0	1.739
7	0.3	0	0	1.739
8	0.5	0	0.5	2.191
9	0	0	0.5	0.524
10	0.7	0	0	1.2

**Table 12- Self Ligating Brackets
(0.016”Ni-Ti)**

(III) - B

0.016” NiTi	Static	Kinetic		
Trials		5mm	9mm	Max
1	0.5	0.1	2.2	2.2
2	0	0	0	0
3	0.1	0	0	0.1
4	0	0	0	0
5	0	1.038	1.038	1.038
6	0	0	1.213	1.213
7	0	0.05	0.05	0.05
8	0	0.04	2	2
9	0	0	0	1.8
10	0	0	0	1.75

**Table 13- Self Ligating Brackets
(0.017"x0.025" Stainless Steel)
(III) – C**

0.017" x 0.025"SS	Static	Kinetic		
Trials		5mm	9mm	Max
1	0.1	0.1	0.1	1.1
2	0	1.2	1.2	1.2
3	0	0	0	0
4	0.15	0.15	0.15	0.15
5	0	0	0	0
6	0	0	0.3	1.943
7	0.4657	0	0.2	0.4657
8	0	0	0.4	0.962
9	0	0	0.3	1.607
10	0	0	0	0

**Table 14- Self Ligating Brackets
(0.019x0.025" Stainless Steel)**

(III) – D

0.019" x 0.025"SS	Static	Kinetic		
Trials		5mm	9mm	Max
1	0.15	0.4	0.4	1.318
2	0.3	0.11	0.12	1.713
3	0.3	0.14	0.4	2.025
4	0.14	0.14	0.5	2.31
5	1.45	0.4	1.45	2.613
6	1.2	0	0.4	1.84
7	0	0	0.4	0.68551
8	0.15	0.15	0.7749	0.7749
9	0	0	0	2.682
10	0	0	0	2.856

Table15- Statistical analysis for Group III

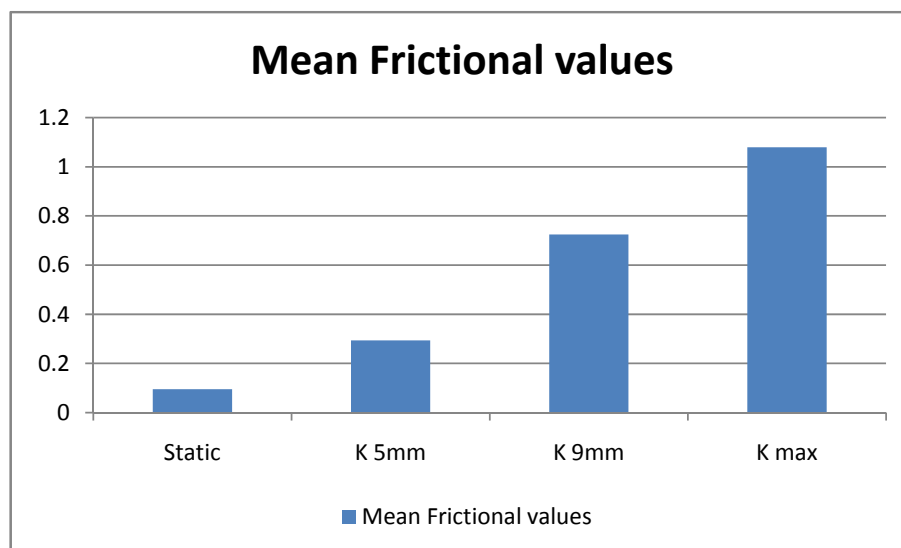
0.014” NiTi	Mean	Median	Standard Deviation	Range	Minimum	Maximum
Static	0.121	0	0.231106	0.61	0	0.61
K 5mm	0.071	0	0.190523	0.61	0	0.61
K 9mm	0.216	0.025	0.270399	0.61	0	0.61
K max	1.38255	1.4695	0.589309	1.667	0.524	2.191
0.016” NiTi						
Static	0	0	0	0	0	0
K 5mm	0.1228	0	0.323307	1.038	0	1.038
K 9mm	0.6501	0.025	0.892251	2.2	0	2.2
K max	1.0051	1.1255	0.918426	2.2	0	2.2
0.017” x 0.025”SS						
Static	0.07157	0	0.148382	0.4657	0	0.4657
K 5mm	0.025	0	0.054006	0.15	0	0.15
K 9mm	0.197	0	0.537774	1.72	0	1.72
K max	0.74277	0.71385	0.719216	1.943	0	1.943
0.019”x 0.025” SS						
Static	0.188	0	0.448548	1.45	0	1.45
K 5mm	0.188	0	0.448548	1.45	0	1.45
K 9mm	0.22249	0	0.495306	1.45	0	1.45
K max	1.881741	1.9325	0.769729	2.17049	0.68551	2.856

Table 16-Statistical comparison for all groups

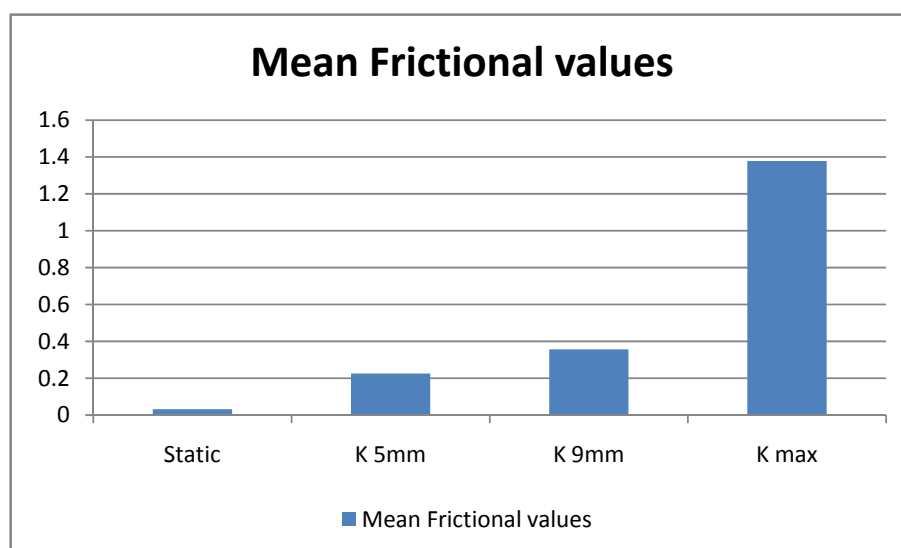
	2 v/s 3	2 v/s 3	1 v/s 3	1 v/s 3	1 v/s 2	1 v/s 2
Static 0.014” NiTi	0.018085	S	0.000737	NS	0.041517	S
K5mm 0.014” NiTi	0.084933	NS	0.509416	S	0.047603	S
K 9mm 0.014” NiTi	0.052503	NS	0.180767	NS	0.040474	S
K max 0.014” NiTi	0.802608	S	0.018586	NS	0.94511	NS
Static 0.016” NiTi	0.043836	S	0.200955	S	7.25E-05	S
K5mm 0.016” NiTi	0.00037	S	0.000168	NS	0.00098	S
K 9mm 0.016” NiTi	0.249916	NS	0	S	0.001514	S
K max 0.016” NiTi	0.997856	S	0.969291	NS	0.772475	NS
Static 0.017”x0.025”	0.002629	S	0	S	0.754904	NS
K5mm 0.017”x0.025”	0.098984	NS	0.318164	NS	0.043458	S
K 9mm 0.017”x0.025”	0.043921	S	0.075298	NS	0.526763	NS
K max 0.017”x0.025”	0.748998	NS	0.264245	NS	0.466281	NS
Static 0.019”x0.025”	0.717308	NS	0.040168	S	0.022507	S
K5mm 0.019”x0.025”	0.000173	S	0.006602	NS	0.020566	S
K 9mm 0.019”x0.025”	0.048461	S	0.264245	NS	0.003354	S
K max 0.019”x0.025”	0.203853	NS	0.040168	NS	0.656816	NS

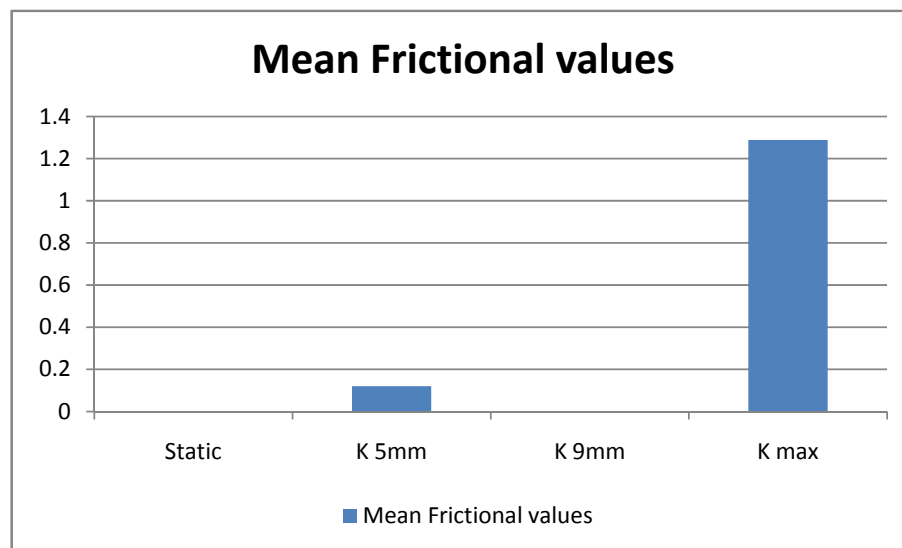
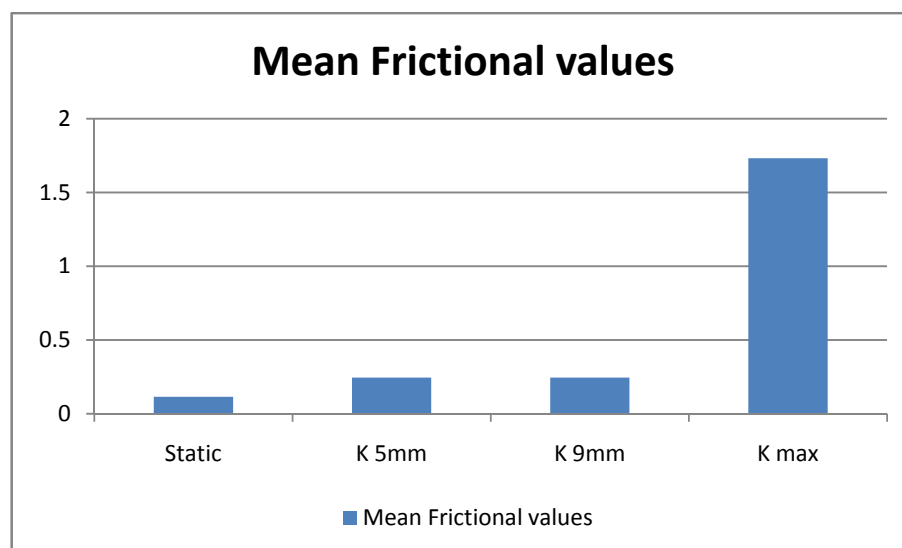
GRAPHS

Graph 1: Conventional Brackets with Unconventional Modules
0.014” NiTi

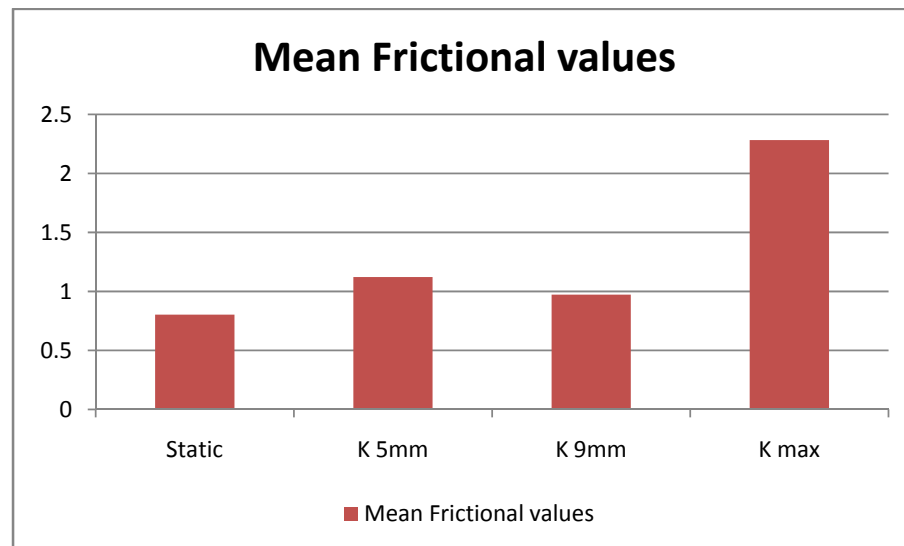


Graph 2- Conventional Brackets with Unconventional Modules
0.016” NiTi

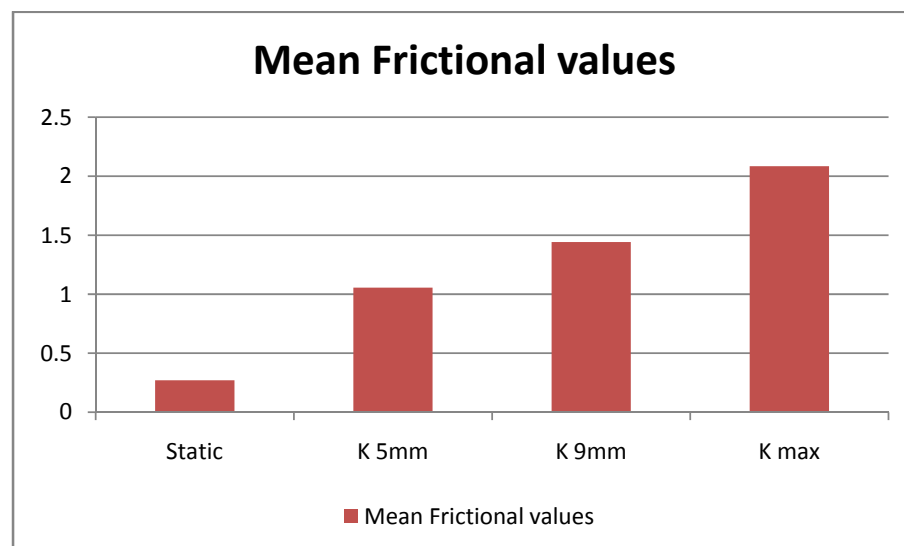


Graph 3- Conventional Brackets with Unconventional Modules**0.017" x 0.025" SS****Graph 4: Conventional Brackets with Unconventional Modules****0.019" x 0.025" SS**

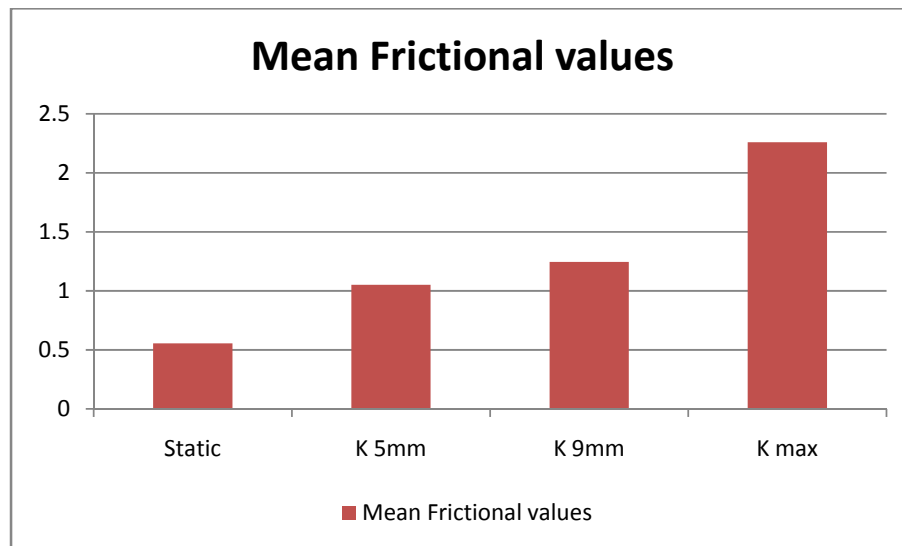
**Graph 5- Conventional Brackets with Conventional Modules
0.014”NiTi**



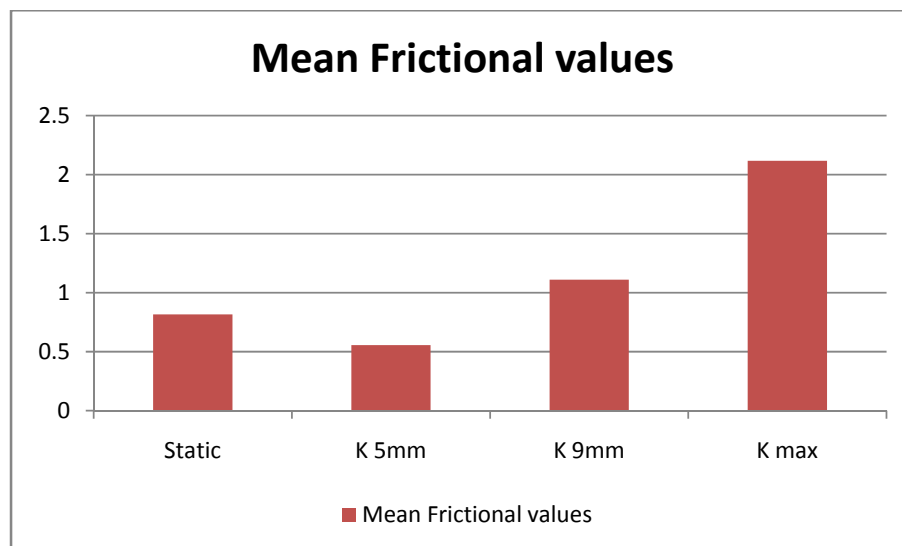
**Graph 6- Conventional Brackets with Conventional Modules
0.016”NiTi**



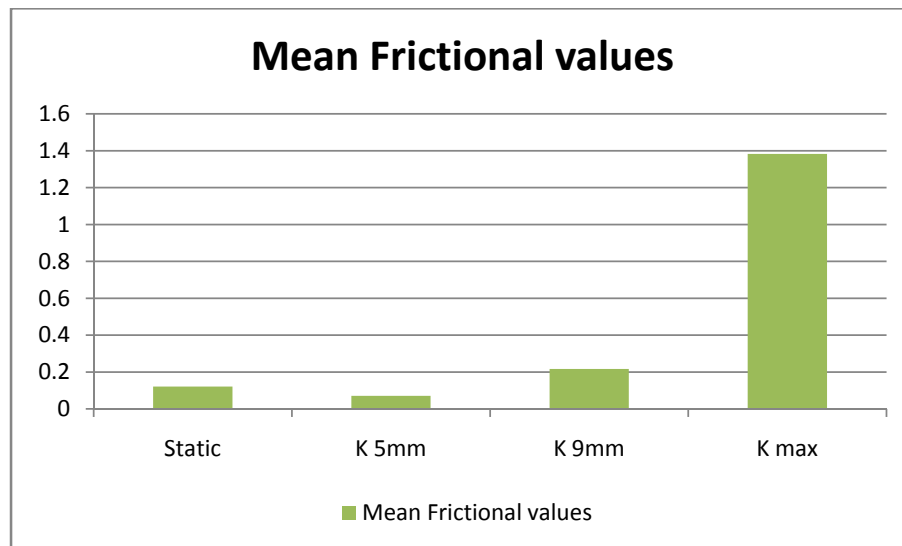
**Graph 7- Conventional Brackets with Conventional Modules
0.017" x 0.025" SS**



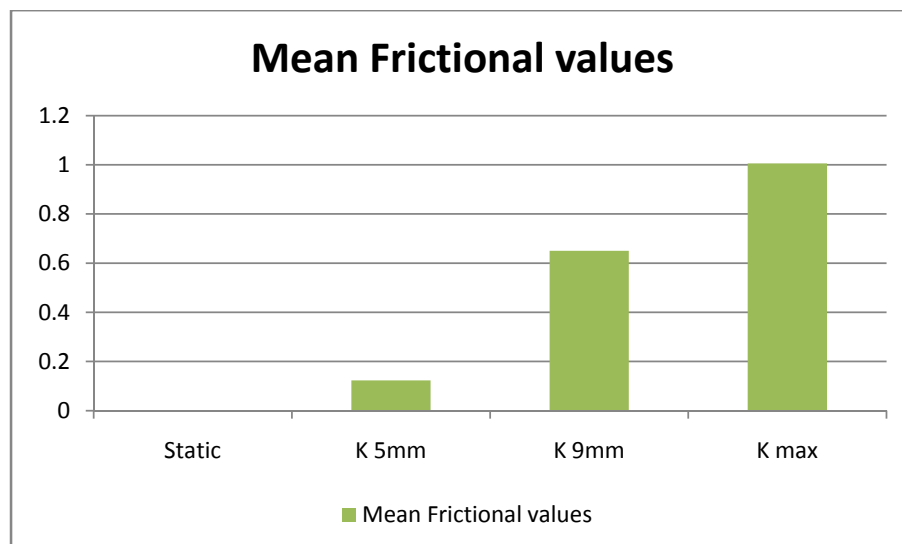
**Graph 8- Conventional Brackets with Conventional Modules
0.019" x 0.025" SS**



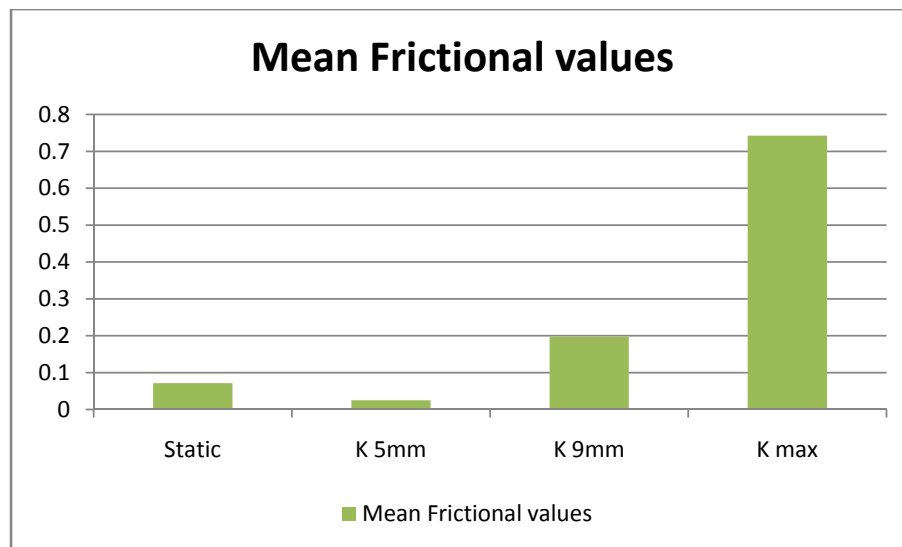
**Graph 9: Self Ligating Brackets
0.014”NiTi**



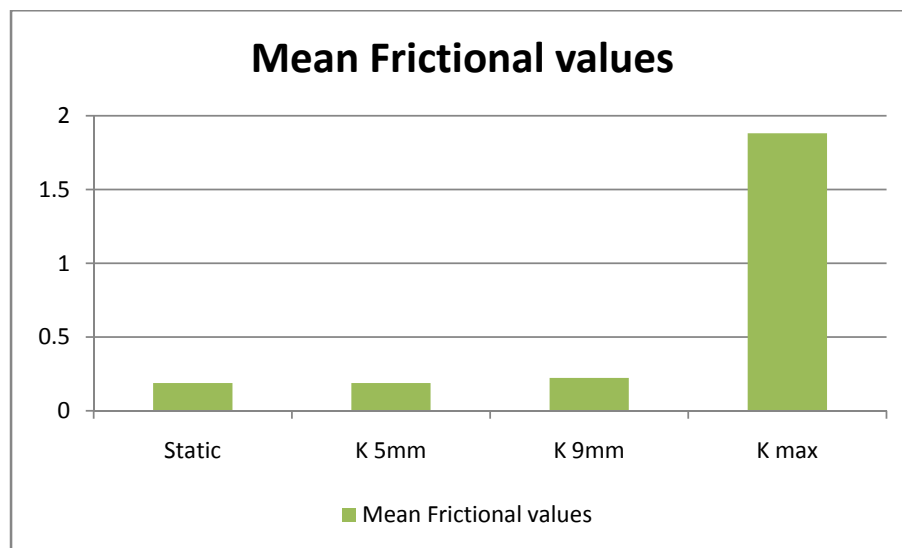
**Graph 10: Self Ligating Brackets
0.016”NiTi**



**Graph 11: Self Ligating Brackets
0.017" x 0.025" SS**



**Graph 12: Self Ligating Brackets
0.019" x 0.025" SS**



RESULTS

All the three groups were tested for its total friction, static friction and kinetic friction. They were divided into four subgroups with four different clinically used archwires- A (0.014" Ni-Ti), B (0.016" Ni-Ti), C (0.017" x 0.025" SS), D (0.019" x 0.025" SS). Each group with its mean, static mean, kinetic mean for the above mentioned wires were listed in Table1 (conventional brackets with unconventional modules), Table2 (conventional brackets with conventional modules), Table3 (passive self-ligating brackets). The three groups were also compared for homogeneity of Means. Another variable to be compared with other means is Kinetic maximum. During traction test of each groups and sub-groups, maximum force is utilized during kinetic movement in few places. That reading is taken as Kmax. The variables in each group were subjected to one-way analysis of Variance (ANOVA).

From Table 5, Table 10, Table 15, the total mean frictional value of Conventional brackets with Unconventional modules calculated was 0.49685, and for Conventional brackets with Conventional modules was 1.5827, and 0.4883 for Self-Ligating brackets respectively. On comparing, Conventional brackets with Conventional modules showed a higher mean than the other two. Conventional brackets with Unconventional modules had a mean little greater than Self-ligating brackets.

The static friction mean for Conventional Brackets with Unconventional modules from table1,2,3,4 was 0.0606, and for Conventional Brackets with Conventional Module from table 6,7,8,9 was 0.6110, 0.0950 for Self-Ligating Brackets from Table 11,12,13,14. On comparing, Conventional brackets with Conventional modules showed a higher static mean than the other two groups. Conventional brackets with Unconventional modules showed a static mean little greater than Self-ligating brackets.

The kinetic friction mean for Conventional Brackets with Unconventional module from Table 1,2,3,4 was 0.6249, and for Conventional Brackets with Conventional Module from Table 6,7,8,9 was 1.4741, 0.5624 for Self-Ligating Bracket from Table 11,12,13,14. On comparison, Conventional brackets with Conventional module showed a higher kinetic mean than the other two groups. Conventional brackets with Unconventional modules had a mean little greater than Self-ligating brackets.

The Kinetic Maximum (K max) mean for Conventional Brackets with Unconventional module from Table 1,2,3,4 was 1.23694, for Conventional Brackets with Conventional Module from Table 6,7,8,9 was 2.1855, and 1.2530 for Self-Ligating Bracket from Table 11,12,13,14. On comparison, Conventional brackets with Conventional module showed a higher kinetic mean than the other two groups. Conventional brackets with Unconventional modules had a mean little greater than Self-ligating brackets.

Descriptive statistics and statistical comparisons of the frictional forces recorded in the different bracket/wire/ligation combinations are reported in table 16. It shows the statistical comparison among the three groups. i) Conventional brackets with conventional modules were compared with passive Self-Ligating Brackets, ii) Conventional brackets with Unconventional modules were compared with passive Self-Ligating brackets, iii) Conventional brackets with Unconventional modules were compared with Conventional brackets with Conventional modules. i) and iii) showed statistically significant difference in values, while ii) was statistically non-significant.

DISCUSSION

Orthodontic sliding mechanics using pre-adjusted brackets is a common method of translating a tooth or a group of teeth. In particular, straight wire technique is achieved by applying a distal force that makes the archwire slide through the slots of the brackets or the tubes of posterior teeth.⁶ When sliding Biomechanics are used with fixed appliances, the main force that contrast tooth movement is the frictional force developed by the interaction of the bracket slot and the orthodontic archwire.²⁹ During orthodontic tooth movement with fixed appliance, frictional forces should be kept to a minimum so that lower levels of force can be applied to obtain a optimal biologic response for effective tooth movement.

Friction is defined as “the tangential force that acts at the surface between two objects when one object slide relative to the other”.²⁴ Several factors influence frictional resistance directly or indirectly. Among these factors, features of archwire, bracket and ligation have been investigated extensively in relation to friction production.^{8, 44}

Most investigations ^{9,24} have concluded that elastomeric modules significantly increase resistance to sliding compared with stainless steel ligatures, especially when the latter are tied loosely. Since the 1980s, self-ligating brackets ^{30, 10, 11, 6, 42} were claimed to reduce friction.

Recently, an innovative unconventional elastomeric ligature (Slide, Leone orthodontic Products) has been introduced into the market. Once applied on conventional brackets this ligature is completely passive. Previous in-vitro studies^{47, 22} had shown that the unconventional elastomeric ligatures (UEL) will

be able to reduce friction with respect to conventional elastomeric ligatures (CEL) during leveling and aligning and during sliding mechanics.

This study was conducted to compare the amount of frictional force generated by a passive Self Ligating Bracket (SLB) with the frictional forces produced by Unconventional Elastomeric Ligatures (Low Friction Elastomeric Ligatures) on Conventional Brackets and also Conventional Elastomeric Ligatures on Conventional Brackets.

A total of twelve samples were made. Difference between the mean produced by different bracket/wire/ligature combinations were divided into three groups. They were

- I. Conventional brackets to be ligated with unconventional modules,
- II. Conventional brackets to be ligated with conventional modules,
- III. Passive Self-Ligating Brackets.

All the three groups were further divided into 4 subgroups. Each group was tested for its static friction and kinetic friction (at 5mm and 9mm) with four different clinically used archwires (0.014" Ni-Ti, 0.016" Ni-Ti, 0.017" x 0.025" SS, 0.019" x 0.025" SS). To standardize the values obtained, ten trials were done for each sample with each wire. Universal testing machine (LLOYD-L.R 50K-England) was used to measure the amount of friction generated with each sample.

All the groups were tested for its total friction, static friction and kinetic friction. Each group with its mean, static mean, kinetic mean for the above mentioned wires were listed in Table1 (conventional brackets with unconventional modules), Table2 (conventional brackets with conventional

modules), Table3 (passive self-ligating brackets). The three groups were also compared for homogeneity of Means. The variables in each group were subjected to one-way analysis of Variance (ANOVA).

The total mean frictional values were obtained. On comparing, Conventional brackets with Conventional modules showed a higher mean than the other two groups. Conventional brackets with Unconventional modules showed a mean little greater than Self-ligating brackets.

In statistical comparison among the three groups, 1. Conventional brackets with Unconventional modules were compared with Conventional brackets with Conventional modules, 2. Conventional brackets with Unconventional module were compared with passive Self-Ligating brackets, 3. Conventional brackets with Conventional modules were compared with passive Self-Ligating Brackets. 1 and 3 showed statistically significant difference in values, while 2 was statistically non-significant.

The results of the present study indicates that both SLB and UEL on CB produced significantly lower frictional forces compared with CEL on CB when coupled with 0.014" NiTi wire, 0.016" NiTi wire, 0.017" x 0.025" SS wire and 0.019 x 0.025 SS wire. These results are in agreement with those that of previous studies^{30, 12, 14, 42, 29} which found that passive SLBs generated less frictional forces than conventional ligatures on CBs. The differences between SLB and CEL on CB are significant in the current study and are very similar to those reported by Paolo Gandini et al⁴¹, Thomas et al¹⁰ and Hain et al.

Recently, an unconventional elastomeric ligature, manufactured with a special polyurethane mix by injection moulding (Slide) was introduced. Once the

ligature is applied on the bracket it simulates the labial cover of a passive self-ligating bracket, thus transforming the slot into a tube that allows the archwire to slide freely.

A previous in vitro study ²², compared the 'frictional forces generated by non conventional elastomeric ligatures (UEL) and conventional elastomeric ligatures (CEL) during leveling and aligning phases with 0.014" super elastic nickel-titanium wire and 0.019" x 0.025" Stainless Steel wire. The results indicated that, when a slight amount of tooth alignment was needed (1.5mm), the differences in the performance of UEL and CEL were minimal, but those differences became extremely significant when correction of misalignment of more than 3mm is attempted. They came into a conclusion that the amount of force generated with UEL during the aligning phase of orthodontic tooth movement was significantly greater than that produced with CEL.

The results of the present study are in accordance with the results of the previous studies ^{29, 47} which was reported with significantly lower frictional values for CB with UEL compared with CB with CEL.

Based on the result, it is concluded that UELs are able to produce significantly lower levels of frictional forces than CEL when applied on conventional brackets; and they produce friction almost similar to self-ligating brackets. Thus UEL may represent a valid alternative to passive self-ligating brackets for low frictionless mechanics. One of the clinical advantages that arise from the use of UELs is that they can be placed on every type of conventional brackets with considerable cost reduction compared with Self-ligating brackets. Another advantage is that clinician can apply friction and low-friction mechanics simultaneously on the same archwire by using CEL and UEL only in particular

segments. For example, during en masse space closure on a rectangular stainless steel archwire, UELs can be used in the posterior segments to reduce friction, while CELs are used in the anterior segment to maximize torque expression and control.

The clinical interpretation of these experimental data, however, requires further considerations that modulate the findings. Minimal adjustments at the bracket/wire/ligature system may significantly change frictional resistance because of physiologic oral functions as well as the oral tissues or food contacting the orthodontic appliance. Thus UELs may represent a valid alternative to passive self-ligating brackets for low friction biomechanics

The advantage in this study is

In Previous study²⁹ they have used only two arch wires [0.014”Ni-Ti and 0.019”x0.025”SS]. In this vitro study, I have used four types of wires for the test 0.014”Ni-Ti, 0.016”Ni-Ti, 0.017”x0.025” SS, 0.019x0.025” SS which we use more commonly during leveling and aligning phase, and during space closure in orthodontic treatment mechanics.

Limitations in this study are

1. During Traction test, while recording static and kinetic frictional forces, sometimes higher variation of frictional force was registered. This could be because of a minute change in alignment of upper member of the universal testing machine(INSTRON) during traction test (FIG 14-A, B,&C.)
2. This study needs further investigation, where in the clinical conditions are replicated in the laboratory in dry conditions.

CONCLUSION

- Unconventional elastomeric ligatures on conventional brackets and self-ligating brackets are able to produce lower frictional force when compared with conventional elastomeric ligatures on conventional brackets when coupled with 0.014", 0.016" Nickel Titanium wire and 0.017" x 0.025", 0.019" x 0.025" Stainless steel wire.
- Unconventional elastomeric ligatures may represent a valid alternative to passive self-ligating brackets for low friction biomechanics.

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